ground water

Technical Note/

A Passive-Discrete Water Sampler for Monitoring Seepage

by Rohit Salve[1]

Abstract

This paper presents the design of the passive-discrete water sampler (PDWS) which has been developed to facilitate investigations of flow partitioning in fractured rocks. The PDWS continuously isolates seeping water into discrete samples while monitoring the seepage rate. The PDWS was used in a flow and transport experiment that investigated fracture-matrix interactions. During the experiment, a mix of conservative tracers with significantly different diffusion coefficients (lithium bromide [LiBr] and pentafluorobenzoic acid [PFBA]) was introduced along a fault located in fractured tuffs, and water seeping through the lower end of the fault was collected by the PDWS and analyzed for tracer concentrations. Preliminary results from this investigation show that samples of effluent captured by the PDWS effectively retained temporal changes in the chemical signature, while providing seepage rates.

Introduction

Within the last three decades there has been an increased appreciation of the importance of matrix diffusion in the subsurface transport of solutes (Neretnieks 1980; Maloszewski and Zuber 1993; Wood 1996 [as reported in Meigs and Beauheim 2001]). Several field studies have investigated matrix diffusion processes in saturated (Albelin et al. 1991; Novakowski and Lapcevic 1994; Hadermann and Heer 1996) and unsaturated (Hu et al 2001) fractured rock environments. At Yucca Mountain, Nevada, a site currently being evaluated for the storage of nuclear waste, insights into the partitioning of flow in unsaturated fractured rocks (i.e., matrix and fracture flow, and fracture-matrix interactions) are important for the design and performance of the potential repository. An understanding of diffusive mass transfer between high-permeability, advection-dominated domains and low-permeability domains is also needed for the development of conceptual models of flow and transport in this unsaturated environment.

The influence of matrix diffusion can be evaluated in field experiments by introducing multiple tracers, with distinct coefficients of diffusion, into a fractured rock flow regime. The collected samples are then analyzed to determine the pattern of tracer breakthrough. For this purpose the collected samples of seepage must span the duration of tracer migration through the test bed and the sampling frequency must be optimized to capture temporal changes in tracer concentrations. However, it is difficult to obtain a complete sample record of subsurface experiments in unsaturated fractured rock because neither the location of seeps nor the start, rates, and duration of flow can be known a priori.

This note presents the design of a passive-discrete water sampler (PDWS) developed for continuous sampling of tracer-laced seepage during a flow and transport experiment through a fault located within unsaturated fractured rock. It also includes preliminary observations from the experiment and discusses the use of the PDWS for other applications that require continuous sampling or fraction collection.

Materials and Methods

Our primary objective was to develop a tracer technique to investigate fracture-matrix interactions in fractured rock. The main design concern was the development of a single tool that could be deployed and left largely unattended over

[1]Earth Sciences Division, Lawrence Berkeley National Laboratory Mail Stop 14-116, 1 Cyclotron Road Berkeley, CA 94720: (510) 486-6416; fax (510) 486-6608; r_salve@lbl.gov

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extended periods of time (days to weeks) to (1) measure seepage rates and (2) isolate discrete samples of water (for chemical analysis) seeping from the ceiling of an excavated underground cavity.

Design of the Passive-Discrete Water Sampler

The PDWS is made up of a vertical stem onto which a series of sampling bottles is attached. The lower end of the vertical stem terminates into a differential pressure transducer. Water enters the PDWS at the top of the stem, travels vertically downwards to the end of the stem, and then begins to rise until the water reaches the inlet to the lowest bottle, from where it is diverted into the first sample bottle (Figure 1a). After the first bottle is filled, additional water fills the vertical stem until the water reaches the inlet to the second bottle (Figure 1b) and so on until the entire series of bottles along the stem are filled (Figure 1c). If a large number of samples are to be collected from a single location, an appropriate number of vertical stems can be connected in series such that after bottles along a single stem are filled, additional water is transferred to an adjacent stem.

The pressure transducer records (as head) the height of water at any given moment along the length of the vertical stem, and is connected to a programmable data logger such that the frequency of measurements can be controlled. Seepage rates during the collection of a particular sample can be determined from the sample volume, and the time to collect the sample (the time during which the transducer shows constant pressure).

The vertical stem used to convey water to the sample bottles is made of schedule 80 PVC (0.25″ ID). The sampling bottles are attached to the stem in a spiral pattern. The number of bottles along the stem is determined by the length of the stem and the volume of water to be included in each sample.

The cylindrical body of the sample bottles is made of clear PVC, with identical caps attached to the two ends of this cylinder. The inner side of the cap is slightly concave, with Swage-Lok fittings located at the center. These sample bottles are connected to the vertical stem with Swage-Lok fittings for easy removal of the water samples. The Swage-Lok fitting in the lower cap is closed with an endcap. The concave cap at the upper end of the collection container serves to direct a floating seal towards the Swage-Lok fitting (Figure 1a). This seal can be made of low-density firm plastic such that as the container fills with water, the seal floats on the surface of the rising water, eventually providing a cap to the water in the container. The concave cap at the lower end of the container is

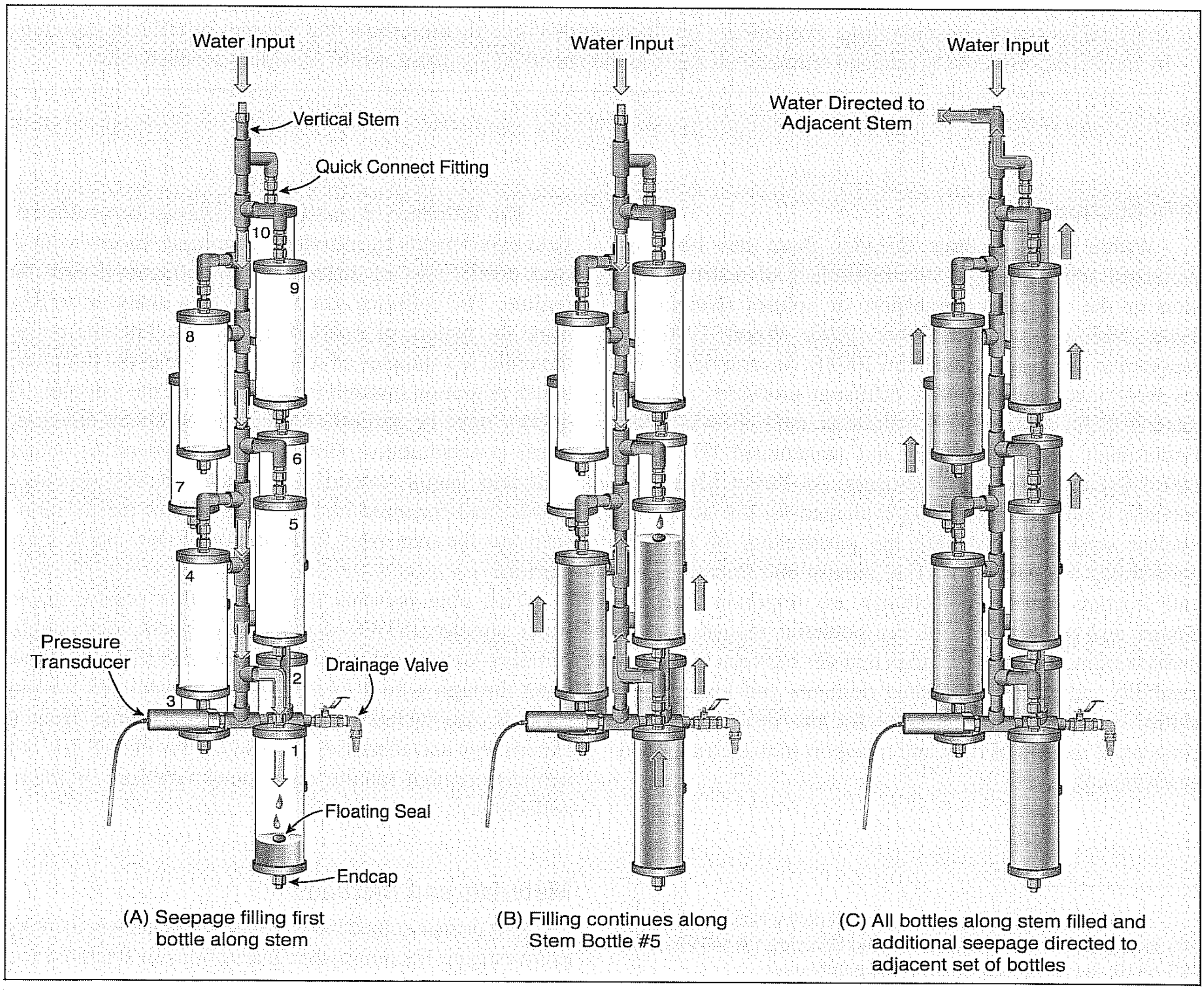


Figure 1. Design and components of the PDWS.

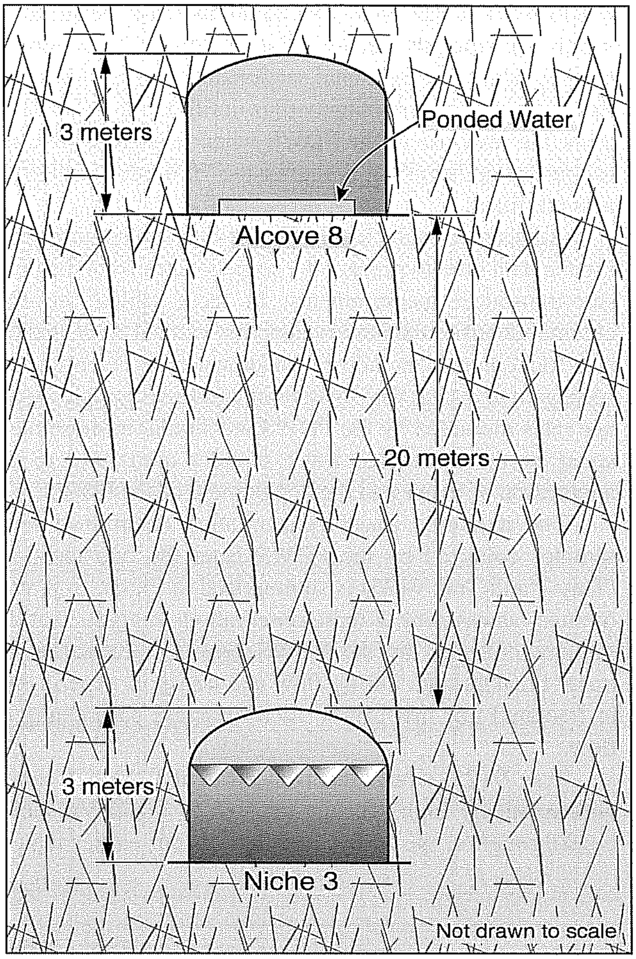


Figure 2. Test bed layout for field investigation of the PDWS. Alcove 8 is an excavated cavity located ~20 m vertically above another excavated cavity (Niche 3). The figure shows the ponded water in Alcove 8 into which tracers were introduced, and the trays along the ceiling of Niche 3 into which seeping water was collected and diverted to the PDWS.

designed to efficiently drain water samples and permit the containers to be easily rinsed.

To access sampled water from the PDWS, the investigator first opens the drainage valve at the end of the vertical stem to remove water stored along the stem. The sample bottles are then removed and capped in preparation for chemical analysis.

Applications

The PDWS was developed for a field investigation of flow and transport through a ~20 m vertical section of fault located in fractured welded tuff at Yucca Mountain, Nevada (Figure 2). One objective of this effort was to evaluate matrix diffusion and the extent of area subject to fracture-matrix interactions. To do this, water containing two conservative tracers with differing diffusivities (lithium bromide [LiBr] and pentafluorobenzoic acid [PFBA]) was released along a fault. Water seeping through the lower end of the fault was collected by the PDWS and analyzed for tracer concentrations.

Prior to the application of the tracer mix, water was continuously released under ponded conditions (i.e., a 4 cm head) along a 5.15 m section of fault visible along the floor of an excavated cavity (Alcove 8) in the Exploratory Studies Facility (ESF) at Yucca Mountain (Figure 2). At a second excavated cavity (Niche 3), which exposed traces of the fault along the ceiling and was located ~20 m below, also within the ESF, an array of trays was installed to collect water seeping out of the fault. Water from each tray was then diverted to collection bottles (1.5 m tall and 0.20 m in diameter) in which transducers located at the bottom measured the seepage rates.

In this investigation, all water used in field liquid tests and for construction purposes contains about 20 ppm of LiBr. The tracer mix introduced into the fault consisted of an additional 500 ppm of LiBr and 25 ppm of PFBA. (The free water diffusion coefficients for bromide and PFBA are 21.5×10^{-10} m^2/s and 7.6×10^{-10} m^2/s, respectively [Callahan et al. 2000]). These concentrations were achieved by dissolving 50 grams of PFBA and 1000 grams of LiBr in 1893 L (500 gallons) of water. This solution with tracers was ponded along the fault in Alcove 8 after quasi-steady-state seepage rates were observed from the effluent collected in Niche 3. This release of tracers began on October 1, 2001, and lasted over a period of nine days. As the application of tracers began, water seeping into three trays in Niche 3 (Tray 6, Tray 7 and Tray 9+23) was diverted to three individual PDWS units (Figure 3). Over the next three months, the trays remained connected to the PDWS units and the water samples collected from these units were analyzed for concentrations of the introduced tracers.

The size of sample bottles and the number of stems connected to each PDWS unit were determined from the times when the test bed was accessible, and from the seepage rate measured at each tray prior to the introduction of tracers. Because access to the underground research facility at Yucca Mountain was typically limited to six to eight hours, four days of each week, the PDWS was designed to collect water samples uninterrupted for at least a period of one

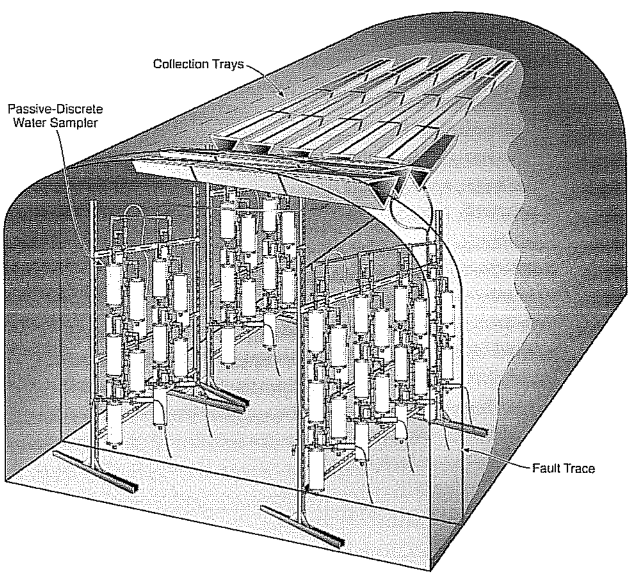


Figure 3. Location of 3 PDWS units (each with multiple stems) located inside Niche 3 to collect water samples from Tray 6, Tray 7, and Tray 9+23.

week. At one collection point (Tray 9+23), where the seepage rates fluctuated ~ 6 L/day prior to tracer release, the PDWS included collection bottles with a volume of 1 L. Four vertical stems were connected serially, with 10 collection bottles attached to each stem (Figure 3). With this capacity to continuously sample effluent into 40 discrete samples, all water seeping into Tray 9+23 would fill the unit over a period of seven days.

In Trays 6 and 7, the measured seepage rates prior to the application of tracers fluctuated between 1 to 3 L per day. To collect water samples at these locations, we configured the PDWS with three stems in series. Each stem had 10 sampling bottles with a volume of 0.5 L. Once the PDWS has this capacity to continuously sample 15 L of effluent into 30 discrete samples, all water seeping into Trays 6 and 7 would also fill the unit over a period of seven days.

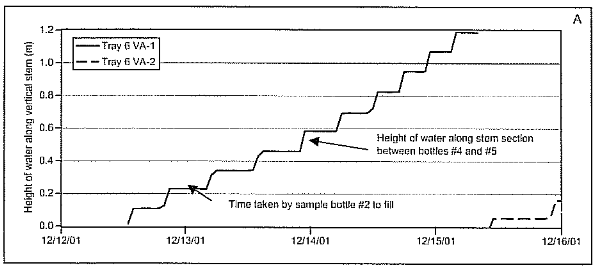
Results and Discussion

The output from the PDWS includes the seepage rate of the captured effluent and continuous discrete samples for chemical analysis. Figure 4 summarizes the measured seepage rates by the PDWS from Tray 6, Tray 7, and Tray 9+23 during the period December 12-16, 2001. The stepped response in the three charts indicates the temporal changes in the height of water in the vertical stems of the PDWS connected to each tray. The rapid increase occurred as water rose along the section of stem between the sampling bottles, while the horizontal sections of the chart show the time taken by the sampling bottles to fill. Figures 4a and 4c show the response of the PDWS when seepage is diverted to the second sampling arm after the 10 bottles in the first arm are filled.

Adjacent to each chart in Figure 4 are tables summarizing the data used to process the seepage rates from the pressure-transducer measurements. In these tables, the first column identifies the bottles along the vertical stem, and the next four columns include information used to determine the seepage rate during the isolation of a discrete sample. Seepage rates measured by the PDWS are similar to those measured by the automated water sampler used prior to the application of tracer and the deployment of the PDWS.

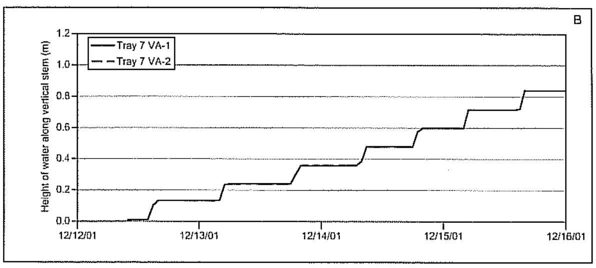
The measured tracer concentration determined from samples collected by the PDWS from the two locations (Tray 7 and Tray 9+23) is summarized in Figure 5. A preliminary assessment of these observations suggests that the samples collected by the PDWS provide information on tracer breakthrough during flow and transport experiments in fractured tuff that can be used to assess partitioning of flow.

Tray 9+23, which received effluent from a location with relatively high seepage rates (6 to 8 L/day), shows breakthrough of the PFBA and Br to occur earlier than at



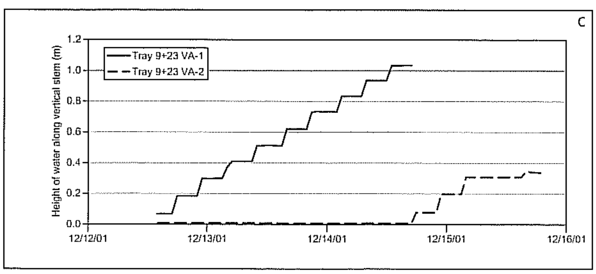
Tray 6

Collection Bottle #	Volume (L)	Start Filling	End filling	Time to fill	Seepage Rate (L/day)
1	0.5	12/12/01 14:00	12/12/01 19:00	5:00	2.4
2	0.5	12/12/01 21:00	12/13/01 4:00	7:00	1.7
3	0.5	12/13/01 6:00	12/13/01 13:00	7:00	1.7
4	0.5	12/13/01 15:00	12/13/01 22:00	7:00	1.7
5	0.5	12/13/01 23:00	12/14/01 5:00	6:00	2.0
6	0.5	12/14/01 7:00	12/14/01 11:00	4:00	3.0
7	0.5	12/14/01 13:00	12/14/01 17:00	4:00	3.0
8	0.5	12/14/01 19:00	12/14/01 22:00	3:00	4.0
9	0.5	12/14/01 23:00	12/15/01 3:00	4:00	3.0
10	0.5	12/15/01 4:00	12/15/01 8:00	4:00	3.0
11	0.5	12/15/01 4:00	12/15/01 9:00	5:00	2.4



Tray 7

Collection Bottle #	Volume (L)	Start Filling	End filling	Time to fill	Seepage Rate (L/day)
1	0.5	12/12/01 16:00	12/13/01 3:00	11:00	1.1
2	0.5	12/13/01 6:00	12/13/01 18:00	12:00	1.0
3	0.5	12/13/01 20:00	12/14/01 7:00	11:00	1.1
4	0.5	12/14/01 9:00	12/14/01 18:00	9:00	1.3
5	0.5	12/14/01 20:00	12/15/01 4:00	8:00	1.5
6	0.5	12/15/01 5:00	12/15/01 15:00	10:00	1.2
7	0.5	12/15/01 16:00	12/16/01 4:00	12:00	1.0



Tray 9+23

Collection Bottle #	Volume (L)	Start Filling	End filling	Time to fill	Seepage Rate (L/day)
1	1.0	12/12/01 14:00	12/12/01 17:00	3:00	8.0
2	1.0	12/12/01 18:00	12/12/01 22:00	4:00	6.0
3	1.0	12/12/01 23:00	12/13/01 3:00	4:00	6.0
4	1.0	12/13/01 5:00	12/13/01 9:00	4:00	6.0
5	1.0	12/13/01 10:00	12/13/01 15:00	5:00	4.8
6	1.0	12/13/01 16:00	12/13/01 20:00	4:00	6.0
7	1.0	12/13/01 21:00	12/14/01 2:00	5:00	4.8
8	1.0	12/14/01 3:00	12/14/01 7:00	4:00	6.0
9	1.0	12/14/01 9:00	12/14/01 12:00	3:00	8.0
10	1.0	12/14/01 13:00	12/14/01 17:00	4:00	6.0
11	1.0	12/14/01 18:00	12/14/01 22:00	4:00	6.0
12	1.0	12/15/01 0:00	12/15/01 3:00	3:00	8.0

Figure 4. Pressure transducer measurements from the PDWS made at three locations. The transducers measure the height of water along each stem as water from the collection trays flows into the PDWS. Note that for this figure the sample collection times have been rounded to the hour.

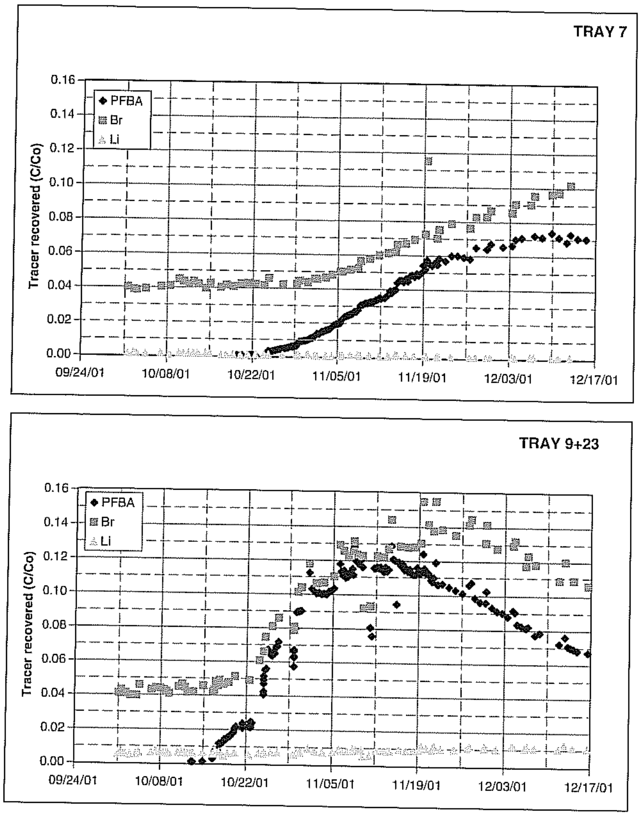


Figure 5. Concentration of tracers measured in continuous samples of seepage collected over a period of three months.

Tray 7, which had a slower seepage rate (~ 1 L/day). In both locations, the samples show the arrival of the PFBA before Br, as would be expected with this combination of conservative tracers with differing diffusion coefficients, flowing through fractured welded tuff. An interesting anomaly captured by the PDWS is in the temporal distribution of the tracer concentrations at the two collection points. In Tray 7, the smooth temporal distribution of both the PFBA and Br suggests that there is likely a well-defined flowpath through which water traveled before seeping into Niche 3. In Tray 9+23 the large fluctuations observed in tracer concentrations suggest that the faster flow was not restricted to a single path. It possibly fluctuated between a number of pathways that were activated at varying degrees by initial pulse of tracers that were flushed through the test bed.

Conclusions

Preliminary observations suggest the PDWS sampler is effective in continuously measuring seepage rates while isolating discrete samples for analysis of tracers. Because the sampler does not have moving parts, the unit was easily installed within an excavated cavity located ~300 m below ground surface and left unattended for up to two weeks. By relying on gravity to convey seeping water sequentially to an array of bottles, the PDWS effectively captured the temporal variability in the concentration of tracers at locations with differing seepage rates.

The PDWS can be easily modified for other applications that require water to be continuously sampled over extended periods of time. For example, in studies observing the breakthrough of tracers along a river channel or from wells, water from the channel or well can be periodically pumped to the inlet in the vertical stem of the PDWS. For such applications, the pump could run continuously, or it could be programmed to sample at a predetermined frequency. The PDWS can also be used to collect rainfall samples (as needed for acid rain or isotope analysis) during a single storm event or during the course of a series of storms. For such applications, the entire unit can be miniaturized and connected to the outlet of a tipping bucket rain gauge.

Acknowledgements

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